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Frequency–dependent limiters for f.m. sound transmitters

W.I. Manson, B.Sc.(Eng.)

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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FREQUENCY-DEPENDENT LIMITERS FOR F.M. SOUND TRANSMITTERS

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Summary

Sound signals applied to f.m. transmitters are normally subjected to high-frequency pre-emphasis. If no form of overload protection is included in the system the transmitters can be overmodulated by high-level, high-frequency audio components, even with programme signals correctly controlled at the studio. In practice, conventional limiters have long been included in the chain to restrict pre-emphasised signals to a prescribed maximum level, at least in the steady state. In conventional limiters, however, the gain-reduction necessary to prevent overmodulation by pre-emphasised high-frequency components also depresses low- and medium frequency components, giving rise, in some circumstances, to an effect commonly known as 'gain-ducking'.

In an effort to reduce this effect alternative forms of limiter have been studied, in which the programme signals are controlled frequency-selectively, rather than attenuated uniformly. Two basic techniques have been examined. In one, limiter control is exercised in discrete bands within the audio-frequency range; in the other, the amount of control is increased progressively with frequency—in the limit simply offsetting the effect of the pre-emphasis to which the signal has been subjected.

The report describes the experimental limiters which were examined, and gives the results of the subjective tests carried out. It is shown that, in particular, the second of the above techniques could lead to a practicable solution to the problem of better overload protection.

Issued under the authority of

P. Rainger

Head of Research Department

Research Department, Engineeering Division,
BRITISH BROADCASTING CORPORATION

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1. Introduction

Modulation of a sound-programme transmitter beyond its nominal maximum can result in audible distortion of the reproduced programme because of non-linearity, particularly in the receiver used by the listener. In the absence of some form of protection, such over modulation may arise from a number of causes; for example, signals of excessive level may be applied to the transmitter modulator simply because of errors of programme-level control or because of a change of characteristic in the circuit carrying the sound signals from the studio. In addition, f.m. transmitters may suffer overmodulation by high-frequency components of programme, raised in level by the 50 μs pre-emphasis specified for the system; here, overmodulation can occur even with programme which is correctly controlled at source and conveyed without significant change to the transmitter. The distortion arising from overmodulation in the latter case is commonly audible as a low-pitched noise, generated by intermodulation between closely-spaced high-frequency components in the programme; the effect can be particularly pronounced on sibilant speech, and it is therefore widely known as 'S-blasting'.

Quick-acting programme limiters have been used for many years to prevent sustained transmitter overmodulation. In the most common arrangement, limiter control is achieved by momentary attenuation of all audio-signal components equally; thus limiter action necessary to prevent over-derivation by pre-emphasised high-frequency sound programme components, depresses low and medium-frequency components unnecessarily. In some circumstances this can give rise to an objectionable subjective effect commonly known as 'gain-ducking'.

In the BBC v.h.f. f.m. radio service, impairment due to gain-ducking is mitigated by reducing the level of the programme signals applied to the limiter; low-frequency components at nominal maximum level are set a few dB below limiting level, which, in turn, is set so as to restrict modulation to the prescribed maximum. By this means, limiter action to control high-frequency audio components is reduced both in frequency of occurrence and in the degree of control required, and, as a result, impairment due to gain-ducking is also diminished. Similar considerations apply to u.h.f. television sound signals.

With the arrangement just described gain-ducking can still prove objectionable on some critical items, even with programme correctly controlled before pre-emphasis. It seems unlikely that the high-frequency content of the sound-programme signals produced will tend to diminish, indeed the opposite may occur, so occasional impairment due to gain-ducking can therefore be expected to continue unless the system of programme control is modified to prevent it.

This report describes an investigation into two forms of protective limiter for possible use on f.m. sound transmitters. In both forms the control introduced is predominantly directed at those signal components which would otherwise have caused over-deviation of the f.m. carrier. By using this selective form of control, it is hoped that full transmitter modulation may be maintained while the objectionable effects of gain-ducking are greatly reduced. The limiters used in the investigation are of a type which control momentary overshoot, so overmodulation of transmitter, both steady-state and transient, is prevented.

2. Experimental frequency-dependent limiters

2.1 Split-band limiters*

One means of reducing gain-ducking comprises a split-band limiter in which the whole audio-frequency band is divided into a number of smaller bands, within each of which an independent limiter acts to restrict the signal level to a set maximum. Thus, limiter action affects the level of only those programme-signal components which would otherwise give rise to overmodulation; as a result the effect on the programme-signal components in other parts of the frequency spectrum is greatly reduced.

Investigations have been carried out on split-band limiters of 2-band and 3-band forms. Fig. 1 shows, in block-schematic form, a possible arrangement for a 2-band system. The incoming signals are pre-emphasised and then split into two bands by filters F1 and F2; the high-frequency components are controlled by limiter L1, and are then re-combined with the uncontrolled low-frequency components in the summing network S1. Limiter L2 controls low-frequency components reaching an excessive level for any reason; it further gives protection against excessive levels arising from the recombination of low- and high-frequency components in the summing network S1.

*The experimental work on split-band limiters was carried out by Mr A.J. Gardner.

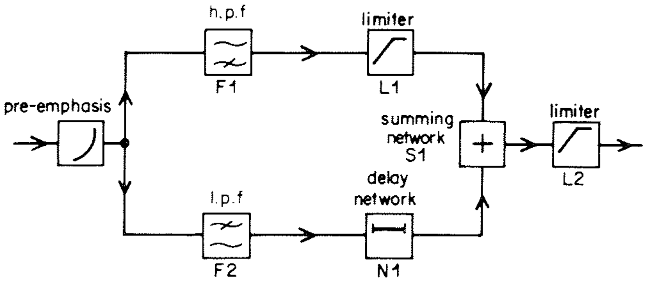

Fig. 1 - Split-band limiter (two band) : block-schematic diagram

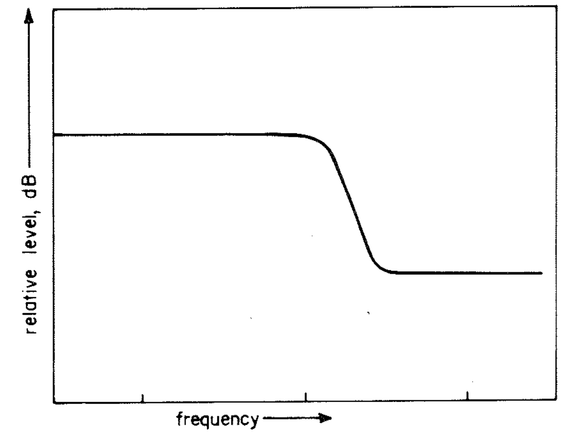

Fig. 2 - Split-band limiter: effect of limiting action on programme-signal spectrum

Fig. 2 indicates the manner in which limiter L1, acting to control high-frequency components, modifies the programme spectrum; low-frequency components are unaffected, while all components in the upper-frequency band are attenuated equally.

If the transmitter is not to be overmodulated even momentarily, limiter L2 must not allow any transient overshoot. A delay-line limiter, in which a special control system, together with a programme-signal-delay line, ensures that overshoot is eliminated,[1,2] was therefore used as L2 in the experimental apparatus. In the present arrangement, a limiter of this type was also used for L1 to eliminate momentary overshoot. Since the upper-frequency channel thus included a delay network, a matching network N1, was included in the direct path to ensure that the correct phase relationship of the signals in the two bands was maintained for re-combination in S1.

Informal listening tests carried out on the two-band system just described, and on a similar three-band system assembled for comparison, indicated that gain-ducking with either system was considerbaly less pronounced than with a conventional whole-band limiter, and further, that the three-band system was preferable to the two-band arrangement.

Though basically simple, the split-band limiter as described is complicated by the need for delay lines in the direct programme path, and for a separate limiter stage at the output to control level after re-combination of the signals in the summing network. For these reasons, optimisation of the dynamic characteristics and of the crossover frequencies for split-band limiters was put in abeyance, and attention turned to examining a technique of progressive or variable-de-emphasis control[3].

2.2 Variable-de-emphasis limiters

2.2.1 General

Appropriate control to avoid overmodulation by components raised in level by high-frequency pre-emphasis, can be achieved by a device which, in effect, does no more than progressively offset the pre-emphasis as necessary. Where the incoming un-emphasised signal cannot be assumed to be free of components of excessive level, such a variable-de-emphasis device can still be adopted, provided that this signal is first passed through a first-stage limiter to ensure that signals applied to the second-stage (variable-de-emphasis) limiter do not exceed the correct level. In the experimental apparatus assembled for the present investigation, the limiter used for the first stage had a complex gain-recovery characteristic[1,2], and, bearing in mind that it operates on the signal before pre-emphasis, it could exercise a considerable degree of level-control with little impairment of quality. If programme-level errors can be assumed to exceed a few dB only very rarely, a control device with a less sophisticated arrangement of gain-recovery might well prove adequate.

For convenience such a control arrangement, comprising an input limiter working on un-emphasised programme followed by a high-frequency pre-emphasis network and a variable-de-emphasis limiter stage, will be described as a 'two-stage variable-de-emphasis limiter'.

2.2.2 Two-stage variable-de-emphasis limiter

Fig. 3(a) shows the general arrangement of a two-stage variable-de-emphasis limiter which was constructed experimentally*. Incoming programme passes through limiter L1 to a 50 μs pre-emphasis network N1 and then to the variable-de-emphasis limiter L2. Both limiter stages are based on a design which does not allow momentary overshoot of output level.

Limiter L2 is arranged to give the required form of control by progressive attenuation of high-frequency signal components. The circuit of the variable-gain element is shown in simplified form in Fig. 3(b). It comprises an 'L' section, with series resistor R and shunt components, capacitor C and variable resistor r. This variable resistor is in fact the drain/source impedance of a field-effect transistor (FET); in operation the limiter control voltage is applied to the gate of the FET in such a way that the drain/source impedance is varied as necessary to effect the required gain control. Component values

*Construction of the experimental variable-de-emphasis limiter and much of the subsequent objective and subjective testing was carried out by Mr. G.R. Mitchell.

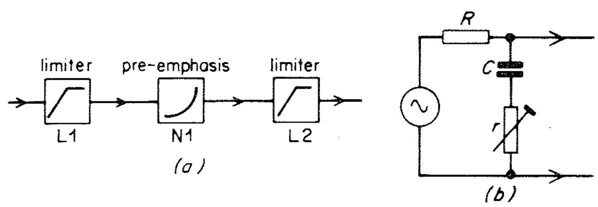

Fig. 3 - Two-stage variable-de-emphasis limiter:
(a) block-schematic diagram
(b) variable-gain element of limiter L2.

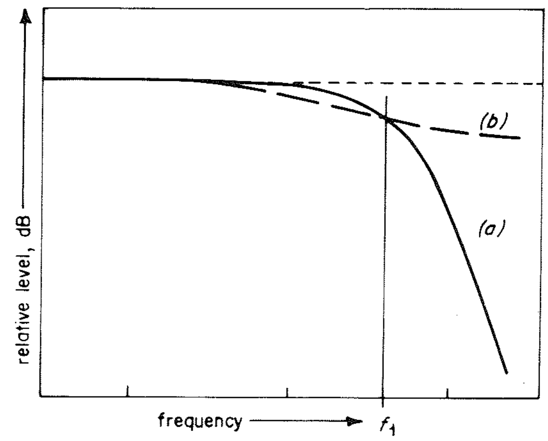

Fig. 4 - Two-stage variable-de-emphasis limiter: effect of limiting action on programme spectrum

——————— *(a) controlling high-frequency components*

- - - - - - - - *(b) controlling a medium-frequency component at frequency f_1*

are chosen so that, in the limit, the top-cut imposed by the circuit C, R and r offsets the pre-emphasis introduced by the preceding network. However, as 50 µs de-emphasis is permanently applied in the receiver, the overall effect is that of a momentary depression of the high-frequency components of programme whenever the limiter operates.

Fig. 4 indicates the way in which the programme spectrum is affected by action of the variable-de-emphasis stage. When a high-frequency signal at substantially full level is controlled, the 50 µs de-emphasis curve, Fig. 4 (a), is imposed. For smaller amounts of control the variable-gain circuit introduces a characteristic of the form shown in Fig. 4(b); thus control of a signal component at substantially full level but of medium frequency, say f_1, is effected without subjecting high-frequency components to the attenuation given by the 50 µs curve.

In limiters operating on un-emphasised programme, the rate at which gain can be allowed to rise after limiting action cannot be made very rapid without risk of cycle-following, and consequent distortion, at low audio-frequencies. Gain recovery time-constants are therefore generally at least several hundred milliseconds. In the present circumstances, however, only high-frequency components are to be controlled significantly in the variable-de-emphasis stage, so the rate of gain recovery can be increased very considerably. In the experimental apparatus a single recovery rate determined by a 25 ms time-constant circuit was used; gain depression after limiting action is thus not prolonged, and any subjective impression of top loss is thereby reduced.

For convenience, a modified delay-line limiter of existing type was used as the variable-de-emphasis stage in the experimental system described above. The attack characteristics of this limiter were determined for un-emphasised programme signals and the incorporated delay-time, some 320 µs, was sufficient to permit gain to be

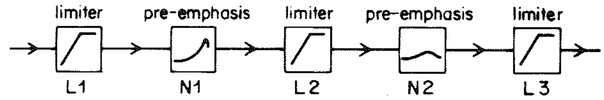

Fig. 5 - Three-stage variable-de-emphasis limiter: block-schematic diagram

reduced by 12 dB in about 305 µs, a rate sufficiently low in these circumstances to avoid audible 'clicks' due to over-rapid change of level.[1,2] However, when such a limiter is used as a variable de-emphasis stage, only high-frequency components are controlled, and these will tend to mask clicks due to rapid gain-reduction. Further, any click arising in the variable-de-emphasis stage is subjected to de-emphasis in the receiver. These factors suggest that a higher rate-of-change of gain, and consequently a delay network simpler than that used experimentally, might be acceptable for the second stage of a two-stage variable-de-emphasis limiter. Since delay-lines are relatively expensive and occupy valuable space, the delay-line for the variable-de-emphasis stage should be optimised before any service-equipment design is finalised.

2.2.3 Three-stage variable-de-emphasis limiter

In the two-stage limiter arrangement described in the previous section, control of high-frequency signals must be accompanied by some attenuation of lower-frequency components. In order to investigate this effect, a three-stage variable-de-emphasis system, shown in block schematic form in Fig. 5, was constructed. Here pre-emphasis is introduced in two cascaded resonant sections having the characteristics, shown in Fig. 6 curves (a) and (b), together giving the standard 50 µs pre-emphasis shown in Fig. 6(c). The respective pre-emphasis networks, N1 and N2 in Fig. 5, are followed by limiters L2 and L3 respectively, each of which has a variable-de-

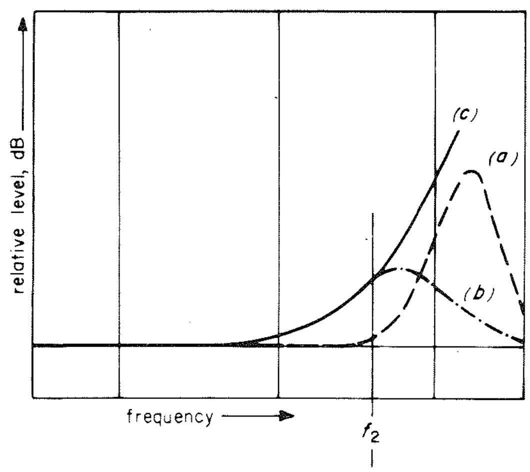

Fig. 6 - Three-stage variable-de-emphasis limiter: amplitude/frequency characteristics of pre-emphasis networks

- - - - - - - - - - *(a) high-frequency pre-emphasis, N1*

— · — · — · — · — *(b) medium-frequency pre-emphasis, N2*

——————— *(c) total effective pre-emphasis, 50 µs*

emphasis characteristic which complements the response of its associated pre-emphasis network. As before, an additional limiter L1, is provided to regulate the incoming un-emphasised signals. In this arrangement the programme spectrum is still subjected to the full 50 μs de-emphasis when a high-frequency signal at full level is controlled; however, when high-frequency components at a lower level are applied, substantially all control necessary can be exercised by the limiter L2, and the lower frequency components, controlled mainly by limiter L3, remain largely unaffected. In this way the effect on the programme spectrum as a whole is somewhat reduced relative to that obtained with the two-stage limiter.

3. Subjective tests

3.1 General

Subjective tests have been carried out principally to compare the performance of the two-stage variable-de-emphasis limiter with the limiter as used at present at BBC u.h.f. television-sound transmitters. In addition the performance of the two-and three-stage variable-de-emphasis limiters have been compared subjectively with one another, and programme-signal quality through the two-stage limiter has been graded with reference to unprocessed programme signals.

3.2 Test Procedure

Three short programme items, selected because the nature of their high-frequency content made them potentially susceptible to gain-ducking and top loss, were used for the subjective investigation. In two of the three items the high-frequency high-level components occurred intermittently - a rhythmic tambourine in a vocal group in one case, and an occassional clash of cymbals in an orchestral performance in the other; in the third item, again orchestral, the intense high-frequency content was again due to cymbal clashing, but this was more sustained than in the previous item.

Tests were carried out with programme applied to the limiters at normal programme-signal level, and at 3, 6 and 9 dB above normal level. For the variable-de-emphasis limiters, normal programme-signal level corresponds to the condition in which the peak level indicates '6' on a p.p.m., i.e. +8 dBr relative to zero level*, and the limiting level for low-frequency components is also +8 dBr. For the present limiter arrangement at BBC u.h.f. television-sound transmitters, normal level corresponds to the condition in which the peak level is again +8 dBr, but the limiting level for low-frequency components is +12 dBr.

Each test comprised a pair of presentations of a particular item, the first through one system and the second through another at the same applied input level. At each test session, after a demonstration of gain-ducking and momentary top-cutting, the observers were asked to listen to the pairs of test-programme items, to decide in which of the two presentations the impairment would detract more from their enjoyment of the programme, and to grade the second presentation, B, relative to the first, A, using the following scale:-

Grade	
+3	B, much better than A
+2	B, better than A
+1	B, slightly better than A
0	B, same as A
−1	B, slightly worse than A
−2	B, worse than A
−3	B, much worse than A

The various system comparisons, the various combinations of test item, and the various programme input levels were presented in an arbitrary order in the test-sessions. Each comparison of the two-stage experimental limiter with the present BBC u.h.f. television-sound arrangement was carried out twice, with the order of presentation reversed in the second test relative to that in the first. Programme through the two-stage limiter was compared with the unprocessed programme only for applied signals of normal level and of level 6 dB above normal.

Sixteen observers, attending in groups of up to six, carried out the tests. Most of the observers had considerable experience in critical assessment of sound programmes; all had some past experience of subjectively grading sound quality.

The tests were carried out in a listening room of volume 85 cubic metres, having a mean mid-band reverberation time of about 0·3 seconds. The programme items were reproduced at a maximum sound level of about 85 dBA* on a high-quality monitoring loudspeaker. The investigation was repeated with the wide-band reproducing circuit modified to simulate the overall frequency response when using a domestic television receiver, including the acoustical response of the loudspeaker. The amplitude/frequency characteristic used was the mean for a number of domestic television receivers examined in 1965; the characteristic of the restricted-band network used for the simulation is shown in Fig. 7.

*Zero level is the level at which a sinusoidal signal dissipates 1 mW in a 600 ohm resistance; it is equivalent to 0·775V r.m.s.

*Measured with a sound-level meter conforming to IEC Publication No. 123 with 'slow' time-constant.

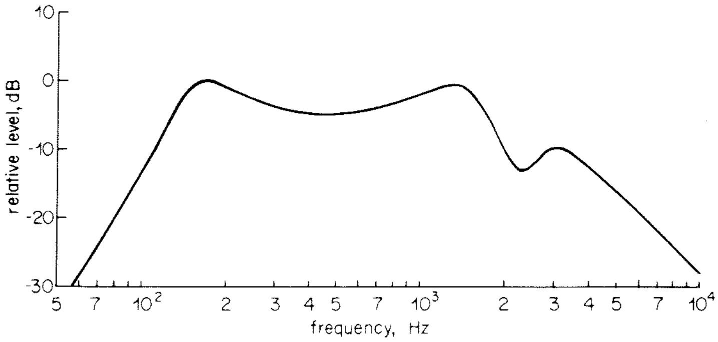

Fig. 7 - Amplitude/frequency characteristic of network used to simulate reception on a domestic television receiver

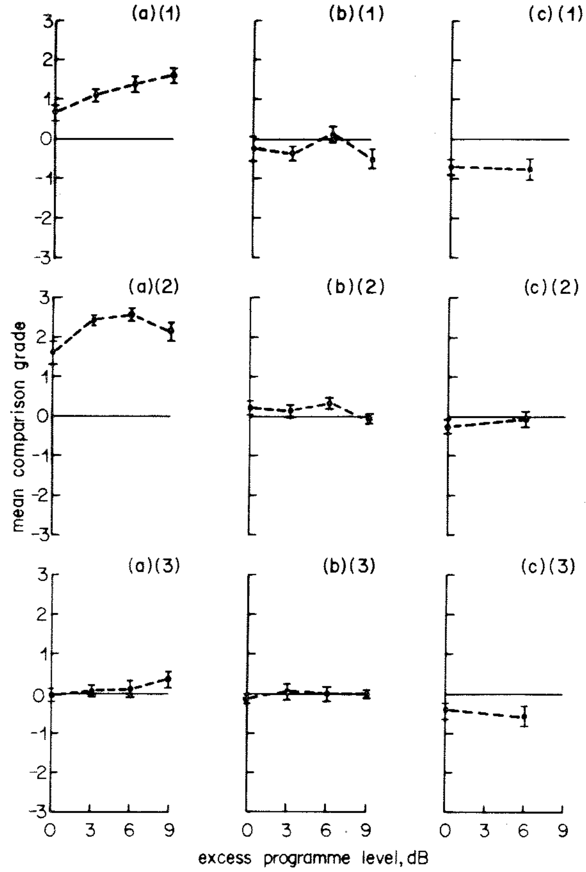

Fig. 8 - Comparison of limiter systems for various programme items, wideband reproduction; mean comparison grade plotted against excess programme level

(a) two-stage variable-de-emphasis limiter relative to the present limiter arrangement (b) two-stage variable-de-emphasis limiter relative to three-stage variable-de-emphasis limiter (c) two-stage variable de-emphasis limiter relative to unprocessed programme (1) Programme item 1, orchestral item with occasional cymbal clash (2) Programme item 2, vocal group with accompaniment, including tambourine (3) Programme item 3, orchestral item with sustained cymbal passages

Ĩ Twice the standard deviation of the mean

3.3 Results

The results of the subjective investigation are presented in Fig. 8, curves (a)(1) to (c)(3) and Fig. 9 curves (a)(1) to (c)(3) for the tests using wide-band and restricted-band reproduction respectively. The mean comparison gradings are plotted against the excess programme-signal level (relative to normal level as defined in Section 3.2), for each comparison. Throughout, the results have been arranged so that the two-stage experimental system is graded relative to the particular system with which it is being compared in each case. The standard deviation of the mean is shown for each plotted result.

The results for wide-band presentation show, for the two programme items containing intermittent high-frequency components, Fig. 8 curves (a)(1) and (a)(2), a definite preference for the experimental variable-de-emphasis limiter rather than the limiter arrangement at present used for BBC u.h.f. television sound; quantitatively this preference was up to 2·5 grades, i.e. between 'better than' and 'much better than'. For the third programme item, Fig. 8, curve (a)(3), which contained more sustained high-frequency passages, there was little difference in grading for the two limiters being compared.

Fig. 8, curves (b)(1), (b)(2) and (b)(3), comparing the experimental two-stage and three-stage limiters, shows no consistent preference for either arrangement; in view of its relative simplicity the two-stage limiter is thus obviously the more attractive.

From Fig. 8 curves (c)(1), (c)(2) and (c)(3) it can be seen that, in general, unprocessed programme is preferred to programme controlled by the experimental two-stage limiter. The difference, however, never reaches 0·75 of a grade, whereas the present limiter arrangement, as noted above, can be as much as 2·5 grades worse than the two-stage limiter.

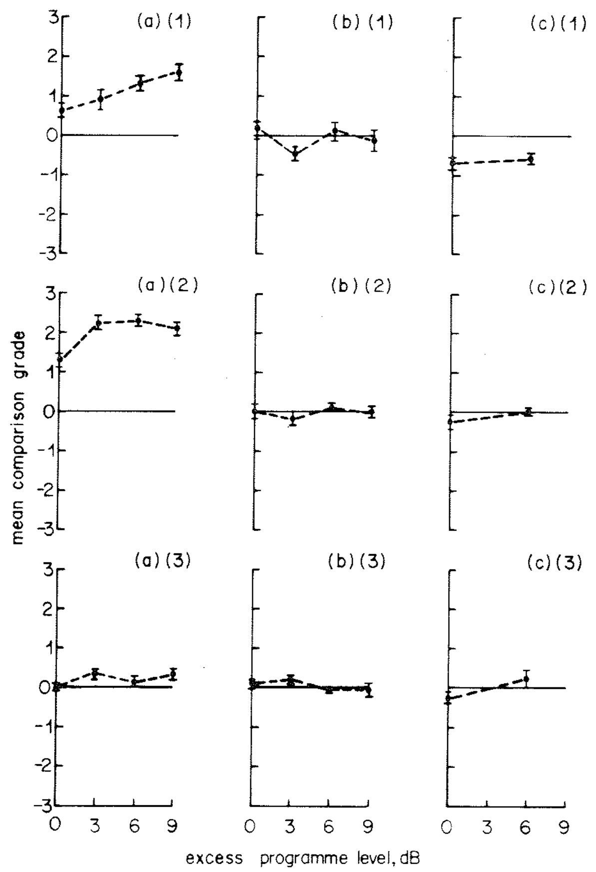

Fig. 9 - Comparison of limiter systems for various programme items, restricted-band reproduction; mean comparison grade plotted against excess programme level

(a) two-stage variable-de-emphasis limiter relative to the present limiter arrangement (b) two-stage variable-de-emphasis limiter relative to three-stage variable-de-emphasis limiter (c) two-stage variable-de-emphasis limiter relative to unprocessed programme (1) Programme item 1, orchestral item with occasional cymbal clash (2) Programme item 2, vocal group with accompaniment, including tambourine (3) Programme item 3, orchestral item with sustained cymbal passages

Ĩ Twice the standard deviation of the mean

The results for tests carried out using restricted-band reproduction, Fig. 9, show very close agreement with those obtained using the wide-band arrangement. This is perhaps not remarkable for tests where the effects of gain-ducking were predominant, but is somewhat surprising where the main effect was that of momentary top loss. Lack of time precluded further investigation of the phenomenon.

4. Conclusions

The system of protection against overmodulation used at present for BBC u.h.f. television-sound transmitters can, in certain circumstances, give rise to an objectionable effect commonly known as gain-ducking.

In the investigation of means to overcome this problem the experimental system studied in greatest detail was a two-stage variable-de-emphasis arrangement, designed to prevent overmodulation, even momentarily. It consists of an input limiter (working on the signal before pre-emphasis) followed by a pre-emphasis network and a variable-de-emphasis limiter. The latter applies a momentary 'top cut', to avoid overmodulation, and in the limit this just offsets the effect of the preceding high-frequency pre-emphasis.

With critical test items the momentary top-cut can be detected when using this experimental two-stage limiter, particularly when unprocessed programme is available for direct comparison, but subjective tests indicate that, for these items, its performance is markedly preferable to that of the arrangement at present used in the u.h.f. television service.

A subjective comparison of programme through the experimental two-stage limiter with direct programme indicated that the difference was only slight (less than 0·75 of a comparison grade) even on material which would be expected to be sensitive to attenuation of high-frequency audio components.

Investigation of a more complex three-stage version of the variable-de-emphasis limiter indicated that its performance was not significantly better than that of the two-stage arrangement, and its extra cost could certainly not be justified.

The investigation described in this report was initiated with u.h.f. television sound particularly in mind, but the same principles can be applied also to v.h.f. f.m. radio broadcasting and, indeed, to any link in the transmission chain which requires over-load protection from pre-emphasised sound signals.

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